

HAM simulation of the drying out capacity of water ingress in wooden constructions

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SUMMARY:

Due to more stringent energy codes, the advantages of wood-frame construction – slender walls in respect to the thermal resistance – have been picked up by the construction market in Belgium. This construction type is not endogenous, and the configuration of building components is often copied from Scandinavian building practice. However, climatic differences may induce additional risks for premature failure due to e.g. water ingress or interstitial condensation. Currently, it remains unclear how much water can be tolerated in wood-frame construction without causing excessive moisture contents. In this paper, the impact of water ingress is evaluated with a 2D hygrothermal model. Static experiments were conducted on the water penetration at window-wall interfaces to relate the water ingress to both wind pressure and the airtightness of the component. A method is proposed to relate these infiltration rates to measured wind pressures to allow for an assessment of the components by means of hygrothermal simulations under a realistic climate. HAM simulation taking into account the expected water ingress loads offers a rapid and realistic method of risk assessment for wooden constructions. Penetrated water was found to be a dominating parameter for the wood moisture content in cases where the initial moisture content and vapour diffusion resistance of the components was altered.

1. Introduction

Compared to masonry buildings, wood frame construction allows for relative slender walls in respect to the thermal resistance. Therefore, despite historical preference for masonry buildings, the share of newly built residential wood frame constructions in Belgium has risen from 5.6% to 11% between 2004 and 2009, and is expected to achieve a market share of 20% by 2020 (WTCB, 2010), mostly driven due to more stringent building codes. Knowledge of the hygrothermal behaviour of wood frame construction remains limited though among building practitioners, and most configurations of wall components are copied from regions with a more prolonged practice of wood-frame construction, such as North-America and Scandinavia. However, climatic differences between these geographic areas are often ignored, increasing the risk of premature building failure. Additionally, Belgian building practice typically consists of SME contractor firms focused on one trade of the building practice, facilitating errors during construction e.g. due to lack of communication or inadequate training. Currently, it remains unclear how robust some construction types are to cope with inadvertent water infiltration, e.g. at window – wall interfaces, and how much water can be tolerated by wood-frame constructions without causing excessive moisture contents leading to deterioration. Therefore, this paper reports on an experimental study on the leak resistance of window-wall interfaces, and a method to relate this risk to climate data is presented. The subsequent drying out capacity of the surrounding wood-frame walls was studied using simulations with a Heat Air Moisture model, allowing for a parametric study of the parameters involved.

2. Experimental results

Depending on the air- and watertightness of the building component water may penetrate into building components due to the co-occurrence of wind and rain. This rainwater can either be drained, buffered or accumulated in the component, potentially leading to deterioration of the building materials, such as due to frost damage, woodrot, Although by no means an indication of the long term hygrothermal performance of a building component, laboratory tests of the watertightness of building components allow relating the amount of water ingress to wind pressures. Typically, this is simulated experimentally by submitting building components to forced air pressure differences, either in a cyclic or static fashion, while simultaneously spraying them with water, thereby simulating wind-driven rain. The static test method EN 1027 (NBN, 2000) consists of applying constant pressures, stepwise increasing every 5 minutes. The applied water spray rate is constant at 2 l/min.m². This allows for the determination of water infiltration rates under constant conditions. The dynamic test method EN 12865 (NBN, 2001) subjects the component to pulsating wind pressures by means of 5 second gusts, repeated in cycles of 15 seconds. The water spray rate consists of simulating direct rain impingement, at a constant 1.5 l/min m², and the simulation of water running off the façade, at a constant 1.2 l/min m². By subjecting the building component to both test procedures, the component is subjected to different climate parameters, each with different failure mechanisms.

Experiments on the air- and watertightness of 2 window-wall interfaces were performed following EN 1027 and EN 12865. Two installation concepts were considered: the watertightness of configuration A is guaranteed by a self-expanding sealant tape, configuration B uses self-adhering flashing. The windows in both components are fixed using metal brackets, the airtightness on the interior side is secured using an airtight foil installed with caulking. Mind that the non-operable window itself was sealed meticulously to avoid any air or water leakage that could affect the measurements. Both setups were tested without insulation in place.

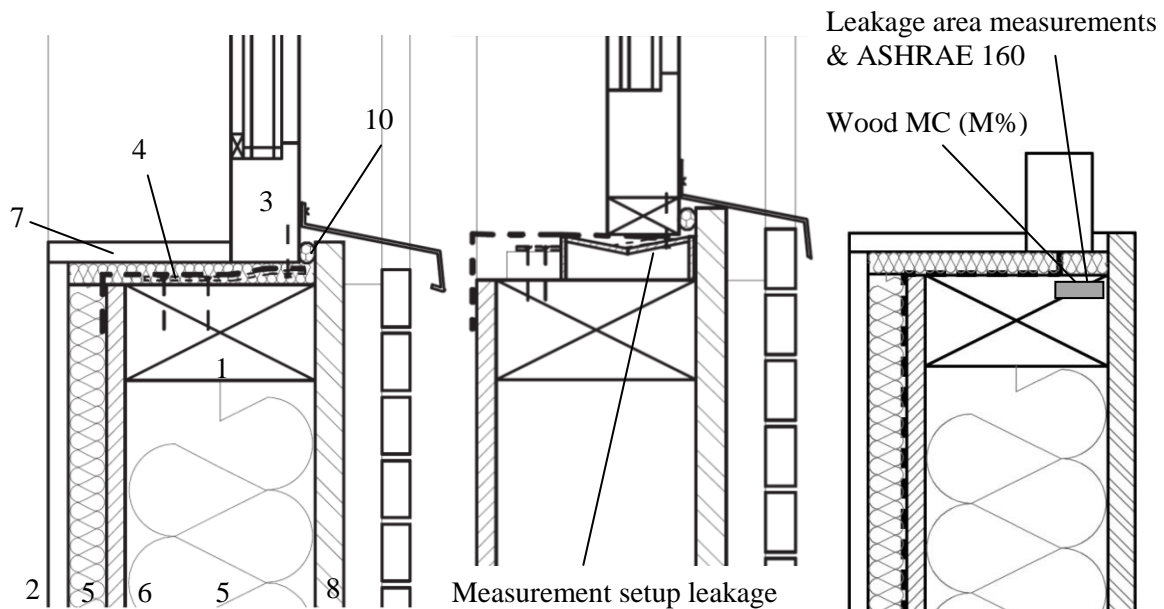


FIG. 1. (l) set up of construction type A, (m) experimental setup of construction type A, (r) input model

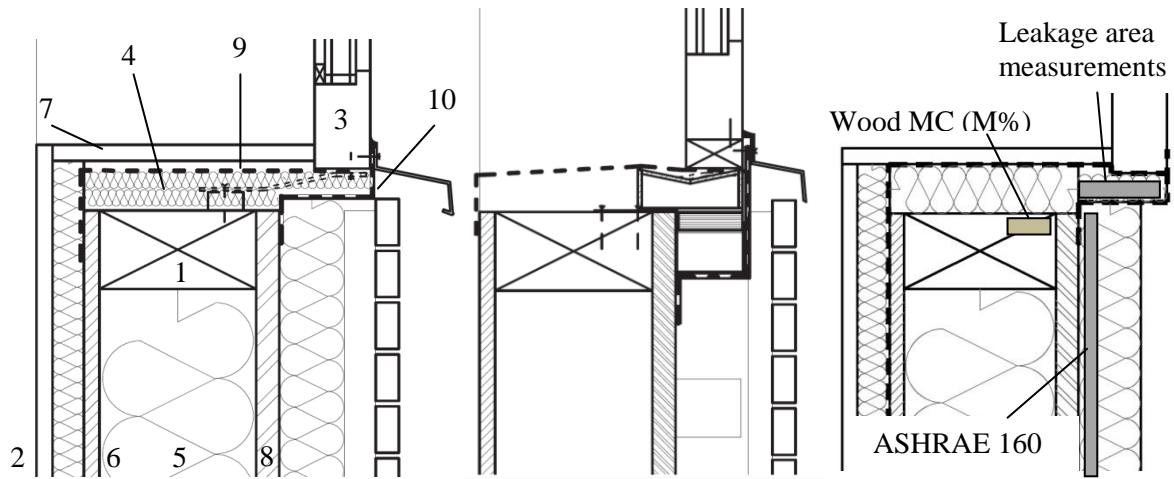


FIG. 2. (l) set up of construction type B, (m) experimental setup of construction type B, (r) input model

TABLE 1. Material properties

	Material	λ (W/mK)	μ (-)	Thickness (mm)
1	Softwood	0.09	200	120
2	Gypsum Board	0.2	8.3	12.5
3	Hardwood	0.13	200	49
4	Polyurethane (PU)	0.03	50	24
5	Mineral wool	0.04	1.3	120
6	Oriented Strand Board	0.13	175	12
7	Plywood	0.13	210	12,5
8	Wood fibre board	0.048	12.5	18
9	Vapour retarder	2.3	20000	1
10	Water resistive barrier	2.3	200	1

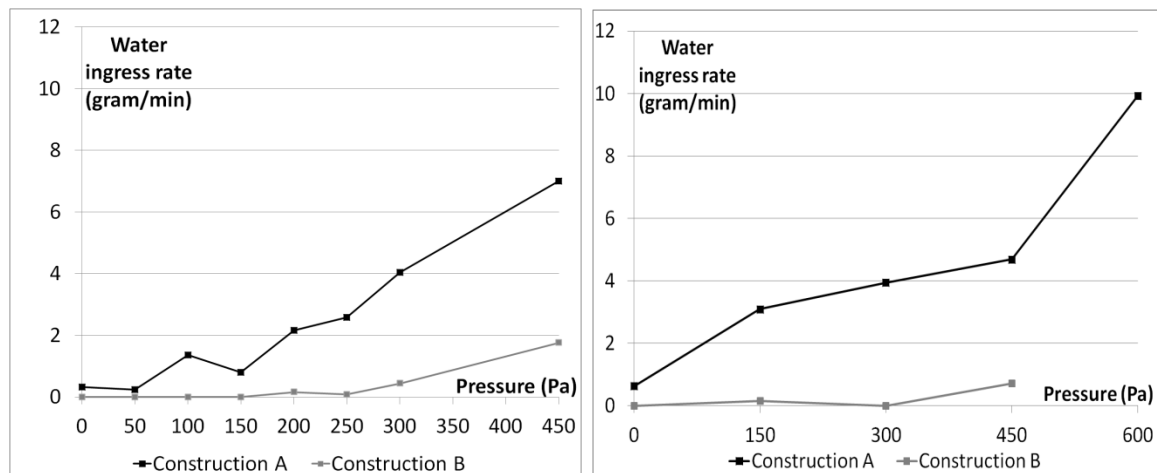


FIG. 3. (l) experimental results of the static method, (r) experimental results of the cyclic method

Results on the static and cyclic test methods are reported in figure FIG. 3. Configuration A is clearly less watertight than configuration B, with 3 – 4 times more water ingress both for the static and cyclic test method. The water ingress rate is not linearly proportional to the applied pressure difference due to the complex reaction of the water tightness membranes and sealant tape due to relaxation phenomena and wind turbulences. In the following only the static test method is considered.

3. Water infiltration

Numerical simulation of the hygrothermal performance of building components is now quite well-established, with several commercial and research packages available. This allows for a quick assessment of the expected performance of a building component over time, for any given climate. One of the remaining difficulties though, is how to take into account the effects of accidental water leaks into the component, and more specifically, how much water can be expected to penetrate. The 2 most important standards for hygrothermal simulations are quite vague on this: the European EN 15026 (NBN, 2007) does not address the subject, whereas the American ASHRAE 160 postulates, as a conservative assumption, that 1 percent of the wind driven rain impinging on the exterior surface will penetrate through that surface if no measured data is available. The specific location where that infiltration is subsequently introduced, is the exterior surface of the water resistant barrier, or equivalent if no water resistant barrier is present. Considering that the tested setups had a total area of 4.5m² the 1% assumption proves to be quite conservative here: for the static test method a penetration rate of 7 g/min at 450 Pa pressure difference is found in component A, as compared to the 90 g/min that would be expected following ASHRAE 160. Additionally, ASHRAE 160 does not consider the locality of leaks, but rather assumes them to be uniformly distributed across the exterior surface of the water barrier. Subsequent accumulation at lower parts of the structure due to gravity are ignored as well. In order to allow for more realistic water penetration rates in the simulations, a relationship between the penetration rates found in the experiments and the actual climatic conditions the component will be subjected to during its service life needs to be developed.

Research on wind speed distributions is rather limited and mainly focuses on extreme wind events, such as hurricanes. Additionally, wind speed data are, at best, only available as sets of 10 minute averaged values, with no information on the peak wind speeds occurring during the 10 minute averaging period. However, research by Davis et al (1968) shows that for higher wind speeds, on a general basis lower gust factors are found, showing an inverse relationship between average wind speed and peak wind speed. Research by Verheij et al (1992) for windspeeds at a height of 20, 40 and 80 meters shows that the distribution of the 10 minute averages can be described using Weibull probability density functions. The distribution of the wind speed fluctuations within these 10 minute periods follows a Gaussian distribution. Nevertheless, virtually no measurements are available on the magnitude of wind peaks for heights under 10 meter. Subsequently, as detailed weather data is scarce, water infiltration rates for building components can only reasonably be based on wind speeds averaged over 10 minute time periods, ignoring temporal variations within the averaging period.

3.1 Static test method

The static test method subjects the building components to static pressure conditions stepwise increasing every 5 minutes. Due to the long duration of every pressure step it seems reasonable that this entails penetration rates at a given pressure difference equivalent to those occurring over averaging periods of at least 5 minutes of the same magnitude under actual wind conditions. Eurocode 1 (2004) allows for calculating the mean velocity pressure based on the mean 10 minute average wind speed using Bernoulli's law:

$$q_{vm} = \frac{1}{2} \cdot c_r(z) \cdot c_0(z) \cdot c_{dir} \cdot c_{season} \cdot v_{b,0}^2 \quad (1)$$

$$c_r(z) = 0.19 \cdot \left(\frac{z_0}{0.05} \right)^{0.07} \cdot \ln \left(\frac{z}{z_0} \right) \text{ for } z_{min} \leq z \leq z_{max} \quad (2)$$

$$c_r(z) = c_r(z_{min}) \text{ for } z \leq z_{min} \quad (3)$$

Where q_{vm} mean velocity pressure for 10 minute averaging periods (Pa),
 $c_r(z)$ roughness factor (-),
 $c_0(z)$ orography factor, taken as 1.0 (-),

c_{dir}	directional factor, taken as 1.0 (-),
c_{season}	season factor, taken as 1.0 (-),
$v_{b,0}$	fundamental value of the basis wind velocity (m/s),
z_0	roughness length (m),
z	height of the wind speed measurement (m),
z_{min}	minimum height depending on the terrain category, taken as 5m for category III,
z_{max}	taken as 200m.

Wind effects are only assumed to pressurize the building façade if their wind direction is within the range of $\pm 45^\circ$ to the normal on the building façade.

The peak WDR load at the center of a façade can be determined using (Van Den Bossche, 2013):

$$WDR = 0,10 \cdot v(z) \cdot i_h \quad (3)$$

Where WDR wind driven rain load, liter/m²h,
 $v(z)$ windspeed at a height z , m/s,
 i_h horizontal rain intensity, mm/h.

The rate of water ingress is determined by linearly interpolating the measurements results for the static test method presented in FIG. 3. In the test campaign the water spray rate is held constant and only the applied wind pressure is varied, in the simulations the water ingress rate is corrected for this relative to the actual occurring rain load.

4. Hygrothermal simulations

The transient temperature and moisture distributions in the wood frame wall assemblies are calculated using version 3.3 of the WUFI 2D software package. The modelled geometries are shown in figures 1 and 2. Weather data for the year 2006 measured at the observatory of the KNMI at Cabauw, the Netherlands (Cesar, 2006) was used for the external climatic conditions, the boundary heat transfer coefficient was set to 23 W/m²K. The wall assemblies are oriented to the southwest, as to achieve the highest WDR loading. Solar radiation as measured at the Cabauw observatory is used. The inside of the assembly is subjected to the normal moisture load as described in EN 15026: 2007, the boundary heat transfer coefficient was set to 8 W/m²K. The hygrothermal simulations are run for a period of 2 years, with 10 minute timesteps. Material properties found in the WUFI-database were used in the hygrothermal simulations, shown in table 1.

4.1 General trends

Water leaks in wood frame walls are especially hazardous if the structural members are prone to excessive water contents leading to woodrot. Typically woodrot is assumed to commence at moisture contents of 20 massprocent (M%). FigureFIG. 4 compares hygrothermal simulations of the local wood moisture content of the structural member in configurations A and B for cases with and without accounting for water ingress (location: see figure 1 and 2). The softwood structural member was initially at a moisture content of 15M%.

Typically, hygrothermal calculations only account for moisture loads due to vapour diffusion from the inner climate to the outside and for the absorption of rain water at the exterior surface. However, in the simulations it was found that occasional water ingress has an important effect on the water content of construction A: the general trend found in the simulation without water ingress is followed, yet during rain events significantly higher moisture loads are found in the structural member. Due to the occurrence of wind peaks rainwater is driven into the building components resulting in very localised moisture loads, which depending on the location and used building materials potentially can result in deterioration. In the more watertight construction B the occurrence of water ingress loads as generated by the static test method proves to be of lesser influence on the wood moisture content. The construction is mainly influenced by the vapour diffusion from interior to exterior.

As a comparison the 1% rain penetration guideline in ASHRAE 160 was applied to the structure. One difficulty faced with this was the exact location of the water penetration. ASHRAE 160 explicitly describes the deposit side of the water to be the exterior surface of the water-resistive barrier. If not present, the deposit side shall be described and a technical rationale given. The deposit side in construction A was chosen to be most indicative of the water leaks, figure FIG. 1 shows the deposit site, which is the same as in the experimental setup. In construction B where a clearly defined rainscreen is present due to the self adhering flashing and water resistant wood fibre board the guidelines in ASHRAE 160 were followed. FigureFIG. 4 shows that despite following ASHRAE 160 a nonrealistic moisture content is found in the wooden component. The moisture content of the structural member in construction A tends to follow a somewhat similar trend as compared to the static method, yet because it has no direct connection to the moisture penetration in the component provides an unreliable result.

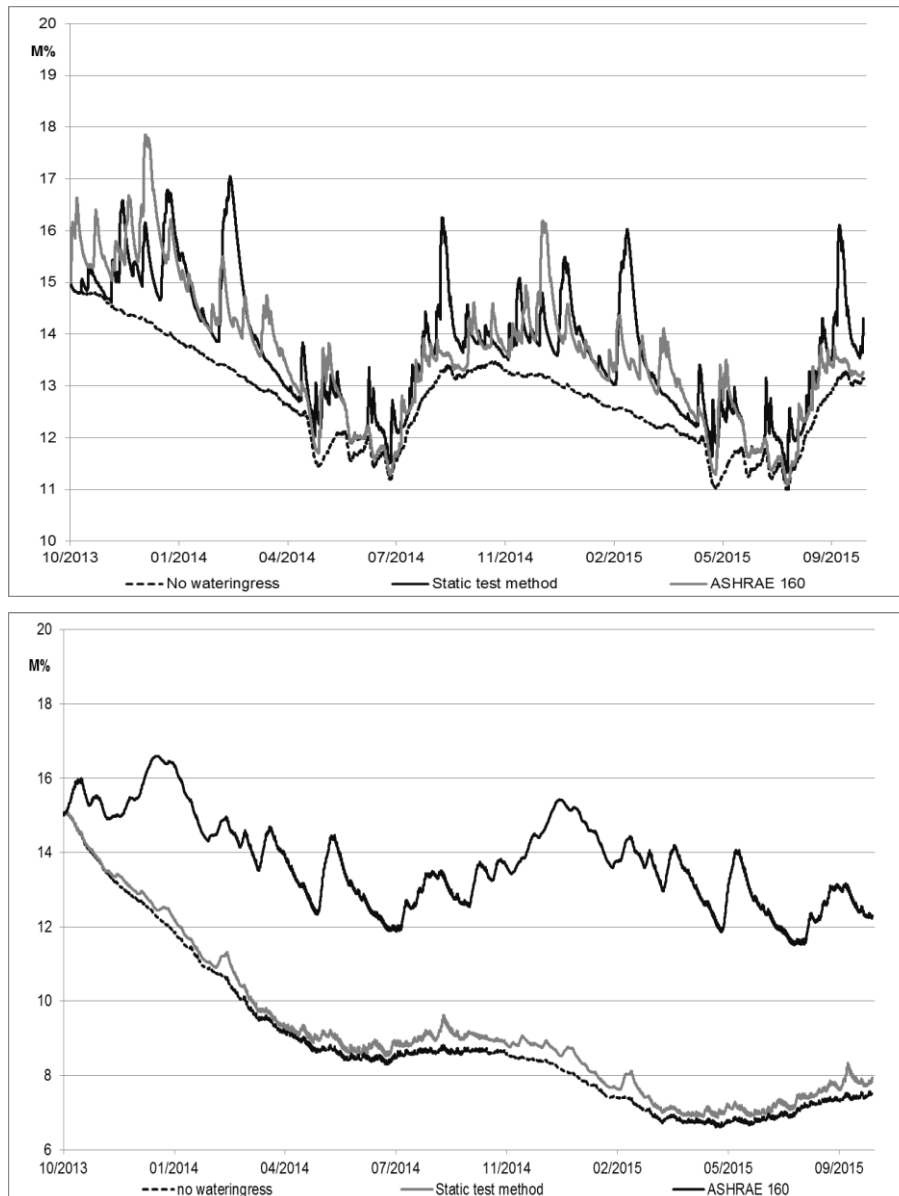


FIG. 4. Hygrothermal simulation results for construction A (above) and B (below)

A parametric study of the material properties influencing the local drying behaviour of the structure was performed for configuration A. Variations were made in the type of insulation material

surrounding the window (polyurethane or mineral wool), the diffusion resistance of the watertight barrier and the initial moisture content. This allows for a qualitative study of their relative importance on the wood moisture content in the case of water ingress. As changing the insulating material from polyurethane to mineral wool equals changing to a more vapour open material with lower thermal performance, the general drying out speed during winter is increased, proving this to be a safer construction type. Similarly, increasing the diffusion resistance of the woodfibre board from 12.5 to 30 slows down the drying of the construction in the case with no water ingress. Though still present, when taking into account water ingress this factor is found to be of lesser importance, as the moisture content of the wooden element is mainly dominated by renewed wetting instead of the vapour diffusion from the interior to exterior. Construction elements initially at a moisture content of 20M% will take significantly longer to dry out when taking into account water ingress, potentially leading to deterioration.

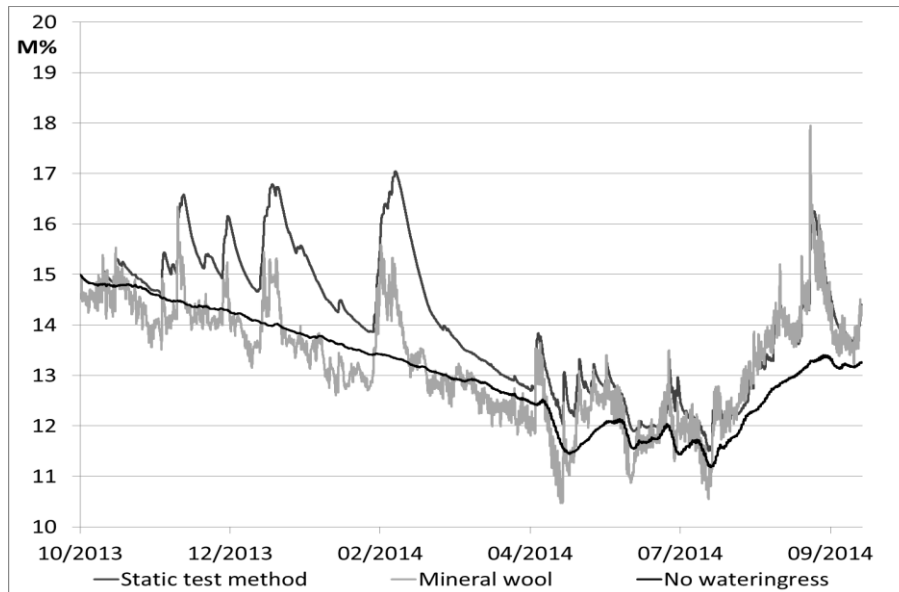


FIG. 5. Simulation result for construction A with polyurethane and mineral wool insulation.

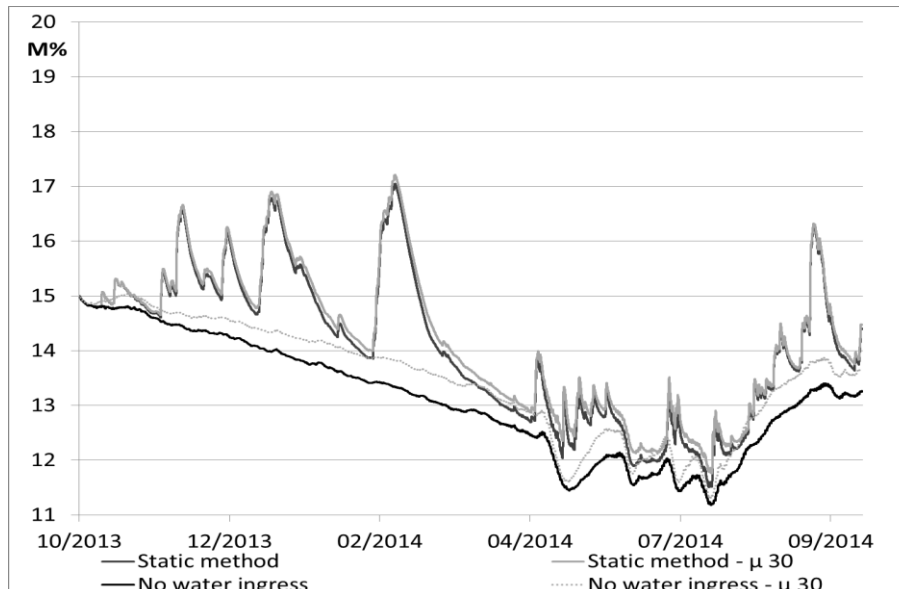


FIG. 6. Simulation result for construction A with $\mu_{\text{wood fibre board}}$ 12.5 and 30.

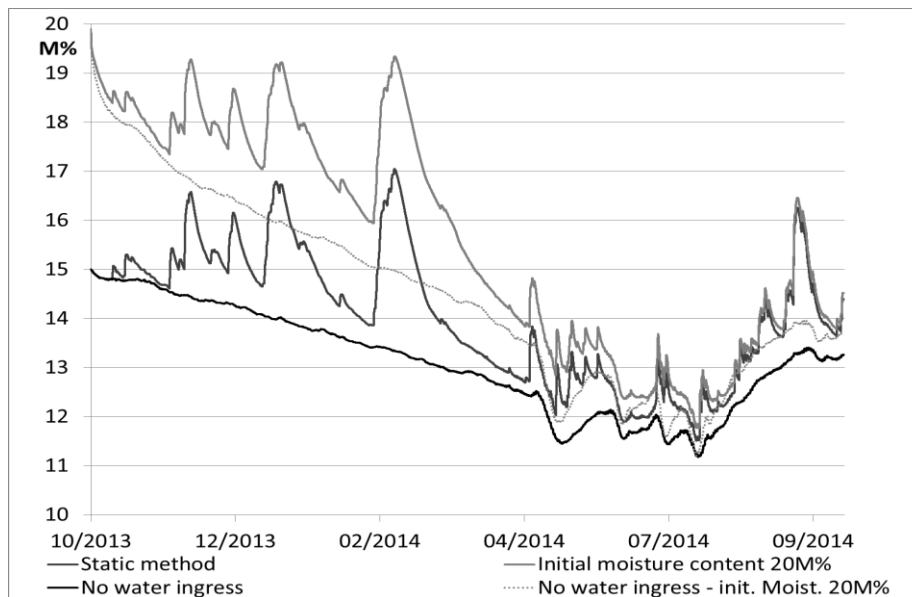


FIG. 7. Simulation result for construction A with initial moisture content at 15 and 20 M%

5. Conclusions

In this paper, a method to relate experimental data on water penetration rates to actual weather conditions is presented. Based on water ingress rates found using the static method EN 1207, a realistic source term is defined correlated to the occurring wind driven rain load for use in hygrothermal simulations. Comparison with ASHRAE 160 shows significant differences in the moisture content of the wooden elements, especially for more watertight components. This is mainly due to the conservative approach in ASHRAE 160 where a fixed penetration rate of 1 % of the impinging water is said to penetrate, with no connection to the actual watertightness of the system. In the parametric study it is found that the water leakage significantly influences the performance of the components.

6. Acknowledgements

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